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SiPM-based azimuthal position sensor in ANITA-IV Hi-Cal Antarctic balloon experiment

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Abstract. Hi-Cal (High-Altitude Calibration) is a balloon-borne experiment that will be launched in December, 2016 in Antarctica following ANITA-IV (Antarctic Impulsive Transient Antenna) and will generate a broad-band pulse over the frequency range expected from radiation induced by a cosmic ray shower. Here, we describe a device based on an array of silicon photomultipliers (SiPMs) for determination of the azimuthal position of Hi-Cal. The angular resolution of the device is about 3 degrees. Since at the float altitude of ~38 km the pressure will be ~0.5 mbar and temperature ~ -20 °C, the equipment has been tested in a chamber over a range of corresponding pressures (0.5 ÷ 1000) mbar and temperatures (-40 ÷ +50) °C.

1. Introduction

The ANITA (Antarctic Impulsive Transient Antenna) project is a scientific balloon experiment dedicated to the measurement of ultra-high energy neutrinos and cosmic rays by detection of radio-frequency signals resulting from interactions with molecules in the Earth's atmosphere and surface ice [1, 2].

Since the radio-frequency signals can be detected both directly and as ice reflections, these measurements provide information about the roughness and reflectivity of the Antarctic surface. The ANITA-II [2] and ANITA-III experiments have determined the surface reflectivity at elevation angles of 12-30 degrees by using the Sun as the radiation source, while lower incidence angles have been studied with the external radiation source Hi-Cal-1 (High-Altitude Calibration). It tracked ANITA for a small fraction of the ANITA-III flight at a distance of 650-750 km providing a direct and ice-reflected signal, which allowed direct determination of the Antarctic surface reflectivity in the radio-frequency mode.

The received ANITA-III signal depends on the relative orientation of the HiCal dipole transmitter relative to the ANITA gondola. For the upcoming ANITA-IV experiment this azimuthal orientation will be determined using the SiPM-based azimuthal position sensor "ATSA".

2. Hi-Cal-2 design

The Hi-Cal payload is shown in figure 1. The payload is attached to a small balloon and consists of an ABS (Acrylonitrile-Butadiene-Styrene) pressure vessel containing two motor-powered piezo sparkers



which produce radio signals in the bi-cone dipole antenna. The operation is controlled by the NASA-standard MIP (Micro-Instrumentation Package) electronics, which manage communications and telemetry, and provide GPS time and position information.



Figure 1. Hi-Cal payload.

3. ATSA board

Since the Hi-Cal payload is constantly rotating, it is desirable to know its azimuthal orientation in relation to ANITA-IV. For this purpose the ATSA device has been designed. It uses 12 silicon photomultipliers (SiPMs) with bias voltage of 5 volts operating as photodiodes. These 1×1 mm SiPMs were designed and assembled at NRNU MEPhI (Moscow Engineering Physics Institute). The ATSA board schematic is shown in figure 2 and a photograph is presented in figure 3.

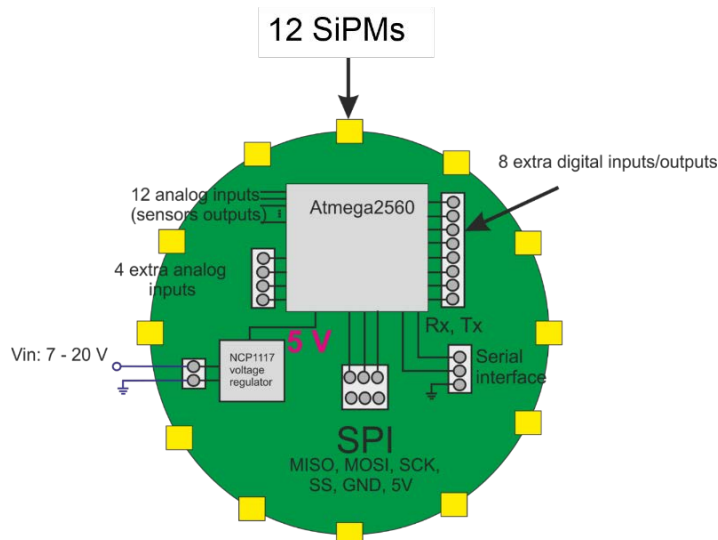


Figure 2. The ATSA board contains 12 SiPMs located 30 degrees apart from each other and powered with 5 V bias. Sensor readouts are directly connected to an Atmega2560 chip with a built-in 16-channel 10 bits ADC. One of the extra analog inputs is used for time-stamping (see below). This board can be powered either with 5 V distributed off the Hi-Cal board or by an external (7 – 20 V) power supply. ATSA has two interfaces: SPI for communication with the Hi-Cal board and a standard serial port for debugging using a personal computer.

In order to avoid electromagnetic noise, the board was placed in a lightweight metal case (figure 4). The total device mass is 110 grams.

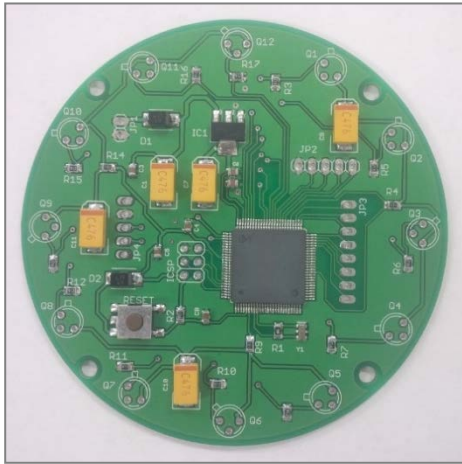


Figure 3. The ATSA board.



Figure 4. ATSA azimuthal sensors.

The light produces current through the SiPMs which is then read out via a $100\text{ k}\Omega$ resistor. The digitized values of the voltage on the SiPMs output are averaged and then fit to a second-order polynomial. The firmware for the device were created using standard Arduino IDE and libraries.

4. ATSA calibration

The calibration of ATSA was carried out using the Sun as a light source. The device was rotated in 3 degree steps in relation to the Sun (figure 5).



Figure 5. ATSA calibration.

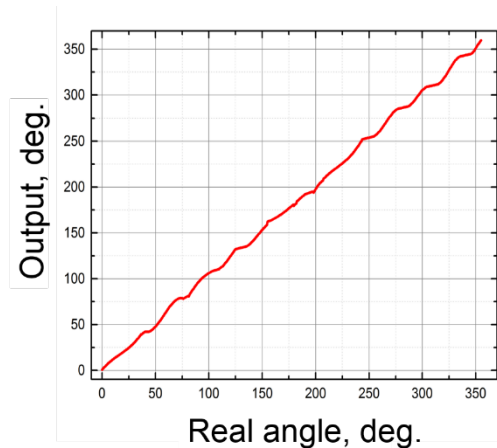


Figure 6. Calibration curve.

The obtained calibration values were interpolated with a 0.5 degrees step and the resulting calibration curve (figure 6) was integrated in the device firmware with a step of 0.5 degrees.

5. Results and tests

Figure 7 shows the correlation between the angle set during manual rotation of the ATSA device and the device output, using the Sun as source. The resulting resolution is under 3 degrees, which is sufficient for the Hi-Cal experiment.

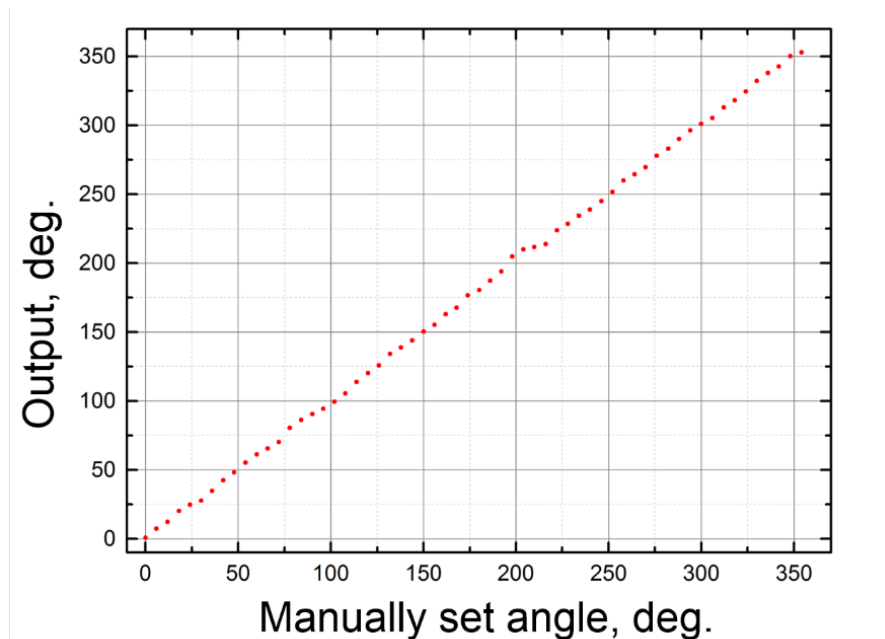


Figure 7. Results of ATSA device implementation.

Since during the flight at the altitude of ~ 38 km the pressure will be ~ 0.5 mbar and temperature about -20 °C, the equipment has been tested in a chamber at different pressures ($0.5 \div 1000$) mbar and temperatures ($-40 \div +50$) °C.

6. Time stamping

Another important function performed by ATSA is time-stamping. A small pick-up antenna that detects radio-frequency signal from the transmitter is located inside the pressure vessel. The signal from it is then transferred to ATSA, where a logic pulse indicating the spark is generated and later processed on the Hi-Cal board. This data is integrated into the GPS stream and used to determine the time of each radio-frequency signal with $50 \mu\text{s}$ accuracy.

7. Conclusion

The ATSA device for the forthcoming Hi-Cal-2-ANITA-IV experiment has been built using SiPMs designed and assembled at NRNU MEPhI. It will be used to determine the azimuthal orientation of the Hi-Cal transmitter in relation to the Sun with an angular resolution of less than 3 degrees. Tests simulating flight conditions (temperature and pressure) have been carried out to verify the equipment's ability to operate at float altitude.

References

- [1] Gorham P W *et al.* 2010 *Phys. Rev. D* **82** 022004
- [2] Nichol R J *et al.* 2011 *Nucl. Instrum. Meth. A* **626–627** S30–5